PRACTICAL EXPERIENCES FROM THE USE OF A METHOD FOR ACTIVE FUNCTIONAL TESTS AND OPTIMIZATION OF COIL ENERGY RECOVERY LOOP SYSTEMS IN AHUS.

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Summary
A method, based on simulation models, for active functional tests and optimization of coil energy recovery loop systems in Air Handling Units (AHUs) have been developed and a first version implemented in the program Engineering Equation Solver (EES). The heat recovery in this kind of systems is often much lower than expected. The main reason for the poor efficiency is faulty fluid flow in the recovery loop. The efficiency can in many cases be raised by tenths of units of percentage. This paper describes experiences from one example of use of the EES based tool in practice, to determine the correct fluid flow. Also, there is a discussion about the measurements in respect of needed accuracy and other related questions.

Keywords: re-commissioning, ventilation, energy, efficiency, EES

INTRODUCTION

The reason to study coil energy recovery loop systems is that they are very common in Sweden and mainly used in cases with high air flow rates such as in hospitals and pharmaceutical industries. The heat recovery in this kind of systems is often much lower than expected. The main reason for the poor efficiency is wrong "fluid" flow in the recovery loop. The efficiency can in many cases be raised from about 35 % up to 60%.

The ratio of the heat capacity flow of supply air divided by exhaust air will if the ratio is 1 in the summer be about 0.8 during cold winder days. Hence, constant air volume systems are variable heat capacity flow systems.

By using a calibrated model of a coil energy recovery loop system it is possible to calculate the optimum fluid flow for all out-door and in-door conditions. Also it is possible to use the calibrated model to check the current behaviour of a heat recovery system compared to design conditions at situations where the conditions are quite different.

The best way to make sure the coil energy recovery system delivers what it should is to implement control of the fluid flow by frequency control of the pump motor. For this case a model of the system is useful to aid the development and implementation of a proper control strategy.

In this paper a case study is presented to show some difficulties with use of a model for fluid flow optimization of a coil energy recovery loop system.

METHOD

In this paper, a method for determine the optimal fluid flow for fluid coupled heat exchangers is described and exemplified by a case study. The method includes 3 steps

1. Estimation of parameters to configure a model of a liquid coupled heat exchanger by use of few discrete data points using a parameter estimation tool
2. Performing analysis using the calibrated model to determine the best operating point using a flow optimizing tool.
3. If necessary, adjusting the flow in the heat recovery loop for highest possible heat recovery efficiency.

TOOL

The tool is handheld and implemented in a Tablet PC, by use of the Energy Equation Solver (EES).

The tool consists of two parts, the first part is used for estimation of the heat transfer parameters of the heat recovery model, and the second part is use for calculation of optimal fluid flow. For the parameter estimation, there is a theoretical minimum need for one data point for each parameter to determine, but the more data points the better. It is important to have data points for a large range of air and fluid flows. For each data point there is need for information about air temperatures, air flows, fluid flow and fluid temperatures.

Figure 1 shows the parameter estimation tool. When the parameters are calculated they can be saved in a file that can be retrieved by the flow estimation tool.

In this version of the parameter estimation tool it is possible to assume that both coils have same configuration and then the same calibration parameters. It is also possible to set some of the parameters to fix values. This can be useful when there is limited data available.

A few parameters describing the coils need to be given. They are pipe diameters, number of flow paths and type and concentration of freeze protection added to the water in the fluid circuit.

The data used for the calibration are put into EES lookup tables; these can be saved for archival purpose.

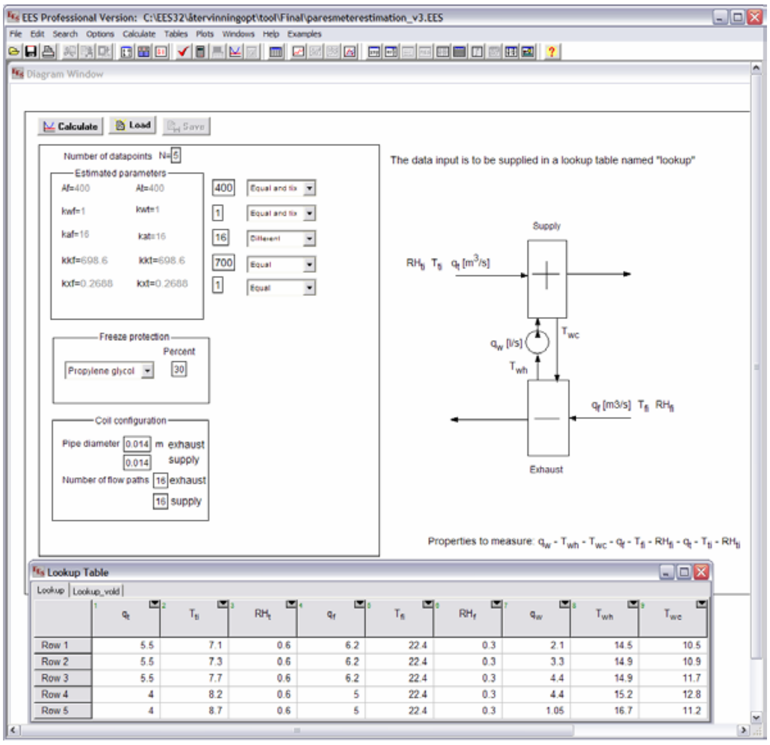


Figure 1. Screen shot of the parameter estimation tool.

The flow estimation starts by reading the parameters already estimated into the tool. There is two ways to continue, to perform a calculation at a certain point or to perform a table calculation of a number of air flows. Figure 2 shows a screen shot of the flow calculation tool.

This tool can also be used to determine the supply and exhaust air flows and the temperatures of the air leaving the coils.

At this point it must be emphasized that this version of the tool does not take condensation into account.

Data needed for optimization is the supply and exhaust air flow and entering air temperatures. If the fluid flow and fluid temperatures can be measured, the air flows can theoretically be estimated using this tool. To use the tool for air flow estimation must be done with caution.

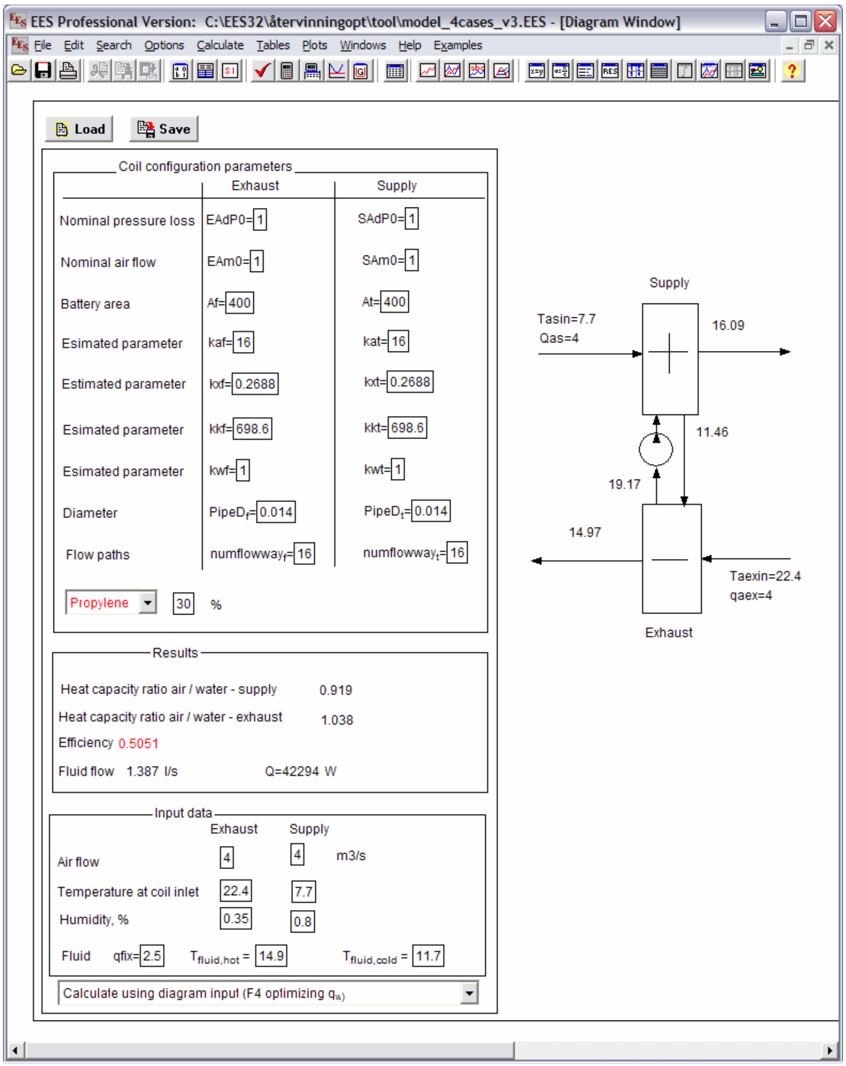


Figure 2. Screen shot of tool for flow optimization before calculation.

MODEL

The model is straight forward and based on heat balances. As the model is implemented in EES it is no need for an explicit description of the equations

Coil energy recovery loop

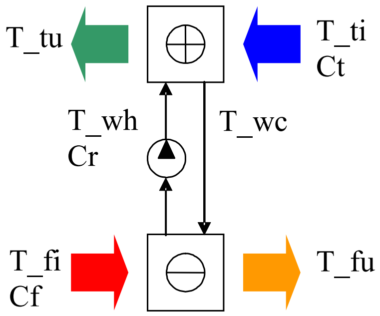


Figure 3. Heat recovery loop

_w=fluid
_f=exhaust air
_t=supply air

T_ti=out door air temperature
T_tu=supply air temperature after heat recovery
T:_fi=exhaust air temperature
T_fu=exhaust air temperature afterheat recovery
T_wh=Temperature in fluid circuit, from cooling coil
T_wh=Temperature in fluid circuit, from heating coil
q_f=Exhaust air flow [m^3/s]
q_t=Supply air flow [m^3/s]
Ct=supply air heat capacity flow rate [J/sK]
Cf=exhaust air heat capacity flow rate [J/sK]
Cr=fluid circuit heat capacity flow rate[J/sK]

kaf=Coefficient exhaust air side
kat=Coefficient supply air side
kxf=Coefficient exhaust air side
kxt=Coefficient supply air side
kwf=Coefficient exhaust air side
kwt=Coefficient supply air side
kkf=Coefficient exhaust air side
kkt=Coefficient supply air side
Af=Area of exhaust air coil
At=Area of supply air coil
PipeD=pipe diameter inside coil

Re_w_f=Reynold number in fluid circuit, exhaust side
Re_w_t=Reynold number in fluid circuit, supply side
Pr_w=Prandtls number of fluid
L_w=Heat conductance of fluid
UA_f=Exhaust air coil heat transfer coefficient
UA_t=Supply air coil heat transfer coefficient
ηt=heat recover efficiency

Heat balance of each fluid

Heat added to the supply air

Q=Ct*(T_tu-T_ti) (1)

Heat transported by the fluid curcuit

Q=Cr*(T_wh-T_wc) (2)

Heat rejected from the exhaust air

$$Q=Cf*(T\_fi-T\_fu) \quad (3)$$

Heat transfer at each coil

As the heat transfer at the air side of a finned tube bank is very complex and there exist (for example in [4]) a numerous of empirical deduced equations both for dealing with the heat transfer at a fin and at a tube bank. A simple correlation is used in the equations (5) and (7) where the heat transfer is supposed to be proportional to the air flow q and $q^{0.5}$. The heat transfer of the fluid in the pipe is more straight forward, also found in [4] but the heat transfer might be enhanced by use of coil spring or longitudinal fins and hence equation (6) and (8) might be unvalid.

Cooling coil

$$UA\_f=Af/(1/Ufa+1/Ufr+1/kkf) \quad (4)$$

$$Ufa=((kaf+kxf)*q\_f^{0.5}+kxf*q\_f) \quad (5)$$

$$Ufr=(0.023*L\_w/PipeD\_f*((kwf*Re\_w\_f)^{0.8})*Pr\_w^{0.4}) \quad (6)$$

Heating coil

$$UA\_t=At/(1/Uta+1/Utr+1/kkt) \quad (7)$$

$$Uta=((kat+kxt)*q\_t^{0.5}+kxt*q\_t)+$$

$$Ufr=(0.023*L\_w/PipeD\_t*((kwt*Re\_w\_t)^{0.8})*Pr\_w^{0.4}) \quad (8)$$

Temperature relations at each coil

The temperature relation in equation (9) and (10) is appended from the deduction of the log mean temperature relation [5]

Cooling coil

$$(T\_fu-T\_wc)=(T\_fi-T\_wh)*exp(UA\_f*(-1/Cf+1/ Cr)) \quad (9)$$

Heating coil

$$(T\_wh-T\_tu)=(T\_wc-T\_ti)*exp(UA\_t*(-1/Ct+1/Cr)) \quad (10)$$

Heat recover efficiency

In equation (12) the heat recovery efficiency is set as transferred heat divided by maximum transferable heat.

$$Cmax\_o=max(Cf,Ct) \quad (11)$$

$$\eta t =min(Ct*(T\_tu-T\_ti),Cf*(T\_fi-T\_fu))/(Cmax\_o*(T\_fi-T\_ti)) \quad (12)$$

MEASUREMENTS

It is difficult to perform measurements on the air side of the heat recovery coils. A study from KTH (Royal Institute of Technology) [3] presents a good view of the problems, shown in figure 4. It is not possible to perform accurate measurements of the temperatures before and after the coils at one single point, there is a big risk that both the temperature and the air flow vary along the coil surfaces, hence no representative temperature can be found. Figure 4 show one example of detailed measurements of temperature (d,e) and velocity (a,b) at cross sections before and after a heat recovery coil. Also presented is the enthalpy transferred to the air by the coil (c) at different locations of the cross section. This enthalpy is calculated by use of additional measurements of the wet bulb temperature.

Based on the difficulty to perform measurements of the air property around the coils, one might come to the conclusion that instead of making expensive and unreliable measurements on the air side near the coils it is possible to perform indirect measurements and using calculations to get hold of the information needed. This approach will be more efficient if there are available accurate simulation models of the components in the air handling unit.

Information needed to calculate the heat recovery efficiency:

- Supply and Exhaust air flow, **q_t**, **q_f**.
- Temperature before and after the coils at supply and return side, **T_ti**, **T_tu**, **T_fi**, **T_fu**.

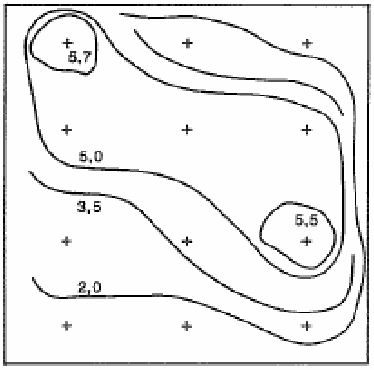
Additional information needed for model calibration:

- Flow in fluid circuit, **q_w**.
- Temperatures in the fluid circuit, **T_wh**, **T_wc**.

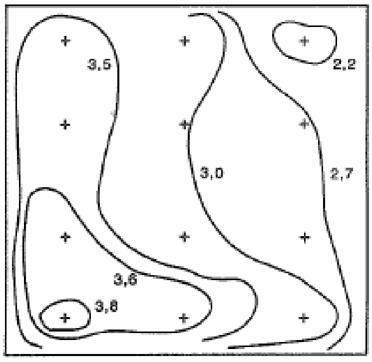
A few data points close to the coil can normally be measured with acceptable accuracy:

- Outdoor air temperature in duct inlet **T_ti**.
- Return air temperature at inlet to HVAC unit, **T_fi**.
- Flow in fluid circuit, **q_w**.
- Inlet fluid temperature to supply coil and outlet temperature from return coil; **T_wc, T_wh**.

To perform the analysis there is still need for the temperatures after the coils or the air flows. It is expected that the measurement of the air flows is more reliable than the temperature measurements but it’s likely to be more expensive. If the supply- and exhaust air flow are known by any kind of measurements, the air temperatures after the coils can be determined using heat balances.



a)



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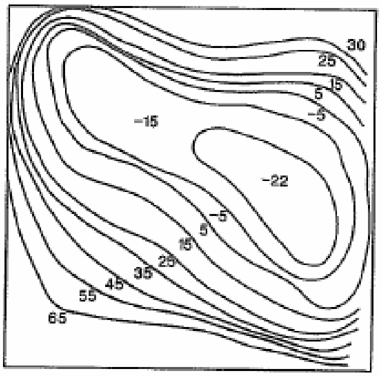
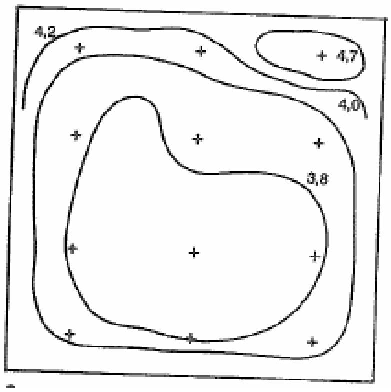
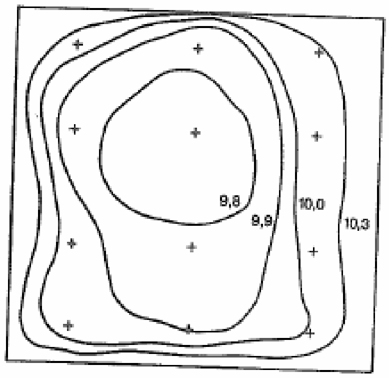


c)



d)



e)

Figure 4. Velocity (a,b), Temperatures (d,e) at different measuring points before and after a heat recovery coil and resulting enthalpy transfer to the air(c). Excerpts from [3].

CASE STUDY

This case study is performed to point out what problems that arise when the method is tested in practice.

The implementation of this method depends on the specific configuration of the air handling unit studied. It might be difficult to perform correct measurements of all properties needed; hence some properties need to be calculated using energy balances. The air handling unit of this case study is designed for about 5.4 m^3/s but run at approximately 4 m^3/s according to, a simple built in air-flow meter. At this air flow rate, each percentage rise of efficiency will decrease the use of energy by 5MWh/year.

The fluid flow is estimated to a constant value of about 5 l/s before any changes.

The properties needed for the parameter estimation is the same as described in the previous section; air flow, water flow, temperature at the air intake, exhaust air temperature and the corresponding heat recovery efficiency or outlet air temperatures from the coils. In addition to this, the fluid needs to be checked to determine type and concentration of freeze protection, this can be performed by using an areometer to determine the density of the fluid and determining the glycol concentration from manufacturers' data sheets.

The method described in this paper is based on the assumption that it is possible to adjust the flow in the fluid circuit. Also, it's supposed to be enough space before and after the coils to make it possible to measure the air temperature. In this case there is frequency control of the fans. The pump in the fluid circuit has not such control but the flow can be adjusted by a balancing valve. The fluid flow can be measured indirect by measuring the pressure over a valve with known characteristics. There is not much space after the coil on the supply side and the measurement of the temperature at this location, will probably be poor according to the discussion in the measurement section.

As the built in flow meter is not to be trusted at all, the air flow was estimated using the knowledge of the temperatures in the fluid circuit by applying a heat balance. If the air and fluid flows are hard to measure with any accuracy, the analysis may be performed using relative flow. In this case study the measured and calculated flows are used.

The resulting optimum fluid flow is 1.4 l/s as shown in figure 6.

Figure 5 show the efficiency as function of the fluid flow/Air flow relation. It can be seen that the efficiency drops rapidly when the flow deviates from the optimum by too low fluid flow and not that rapidly when the fluid flow is too high. If the calculated efficiency is to be trusted, there is a nice saving potential of about 5% that can be recalculated to 25 MWh/year.

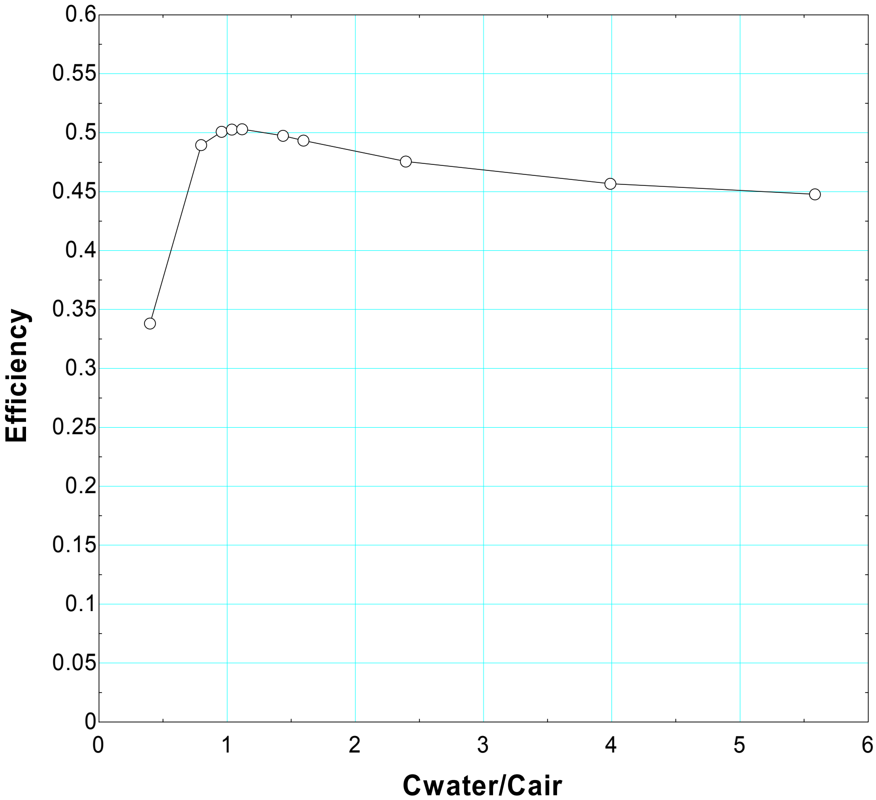


Figure 6. The efficiency of the heat recovery as function of the ratio of fluid flow divided by supply air flow. The optimum can be found close to 1.

The data needed for the parameter estimation is retrieved by measurements and calculation with uncertainties as shown in table 1. The outgoing air temperatures from the coils are measured to estimate the air flow, at a fluid flow as low as possible to get as high temperature difference in the fluid circuit as possible. When the air flow is calculated it is used to calculate the air temperatures

Looking at the uncertainty analysis for the fluid flow calculation, it is evident that the outgoing air temperatures are responsible for about 50 % of the uncertainty, the fluid flow for only 15% and the other temperatures used in the calculation for about 10% each. This high uncertainty for the air flow estimation can be compared to an uncertainty of less than 10% for tracer gas measurements of the air flow.

Table 1: Uncertainty of the data used for the parameter estimation in this case study

Data	Description	Estimated uncertainty
T_ti	Measured	± 0.5 ºC
T_tu	*Measured / Calculated*	*± 2 ºC / ± 2.7ºC*
T_fi	Measured	± 0.5 ºC
T_fu	*Measured / Calculated*	*± 2 ºC/ ± 2.7ºC*
T_wh	Measured	± 1 ºC
T_wc	Measured	± 1 ºC
q_w	Measured	± 0.2 l/s
q_t	*Calculated*	*± 52 %*
q_f	*Calculated*	*± 62 %*

The relative humidity of the air has a limited impact on the accuracy of the calculated air temperatures.

The resulting uncertainty for efficiency calculation using data with uncertainties as in table 1 is as poor as one could expect, the relative uncertainty is in one example about 60%.

What uncertainty could be expected if the calculated data was derived by use of more accurate measurements? Table 2 shows an example of resulting uncertainty when the measurements are performed more accurate.

Table 2 shows that the temperature of the air leaving the coils can be calculated with good accuracy if the air flow and fluid temperatures are measured with fair accuracy.

The resulting uncertainty for the efficiency calculation using data with higher accuracy does increase the accuracy quite a lot. Using data with accuracy as in table 2 above, the relative uncertainty for one calculated example is about 18%.

Table 2: Uncertainty of the data used for the parameter estimation when fair measurements are available.

Data	Description	Estimated uncertainty
T_ti	Measured	± 0.5 ºC
T_tu	*Calculated*	*± 0.85ºC*
T_fi	Measured	± 0.5 ºC
T_fu	*Calculated*	*± 0.85ºC*
T_wh	Measured	± 0.3 ºC
T_wc	Measured	± 0.3 ºC
q_w	Measured	± 0.05 l/s
q_t	Measured	± 10 %
q_f	Measured	± 10 %

DISCUSSION

The case study is based on rough measurements to show what the results could be if the tool and method is used in practice without focus on the uncertainty. It is clear that there is need for accurate measurements to use this tool and method.

If the air flow is estimated wit high accuracy by tracer gas measurements, it is possible to use heat balances to estimate the air temperatures leaving the heat recovery coils at the exhaust and supply side. On the other hand, it is not possible to estimate the air flows by use of heat balances with high accuracy.

In the case study, the ratio of the heat capacity flow rates between the fluid circuit and the supply or exhaust air flow is about 1 as it should be according to the literature [2]. This can be expressed such as the mean value of the temperature change of the exhaust and supply air streams should be the same as the temperature difference in the fluid circuit. This could be implemented as a control algorithm if it was possible to measure the air temperatures after the coils with good accuracy.

The benefit of using a model as in this tool for optimizing the fluid flow in the coil energy recovery loop system with constant air flows is not yet clear. It looks like the method described in this paper has possibility to work if it is possible to perform measurements with low uncertainties, but there is still need for further development. Below is listed two points to be further evaluated:

- What is the measurement accuracy needed to make sure that the calculated optimum of the fluid flow is close the real optimum?
- What would the benefit be by using models of all components of the air handling unit instead of just for the coil loop?

CONCLUSIONS

A model based on common engineering equations of a coil energy recovery loop system has been implemented in Engineering Equation Solver (EES) to form the foundation of a tool for optimizing the flow in the fluid circuit. The tool has been tested in a rough case study from which a number of conclusions can be drawn:

- The measurements need higher accuracy than commonly achievable when making a performance check of an AHU if they are to be utilized for identification of model of a coil energy recovery loop system.
- To get hold of the outgoing air temperatures from the coils for use with the parameter estimation tool, it is possible to use heat balances if the air flow is measured with tracer gas or a method with higher accuracy. It may be difficult to measure these temperatures directly.
- Once there is a well calibrated model available it can be used for estimating the optimum fluid flow for different weather conditions.

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